Creating a Simplified Optimization Model of a Natural Gas Power Plant with Carbon Capture and Energy Storage

Ian Gowen, Athul Sundarrajan, Dr. Azad, Dr. Herber

Department of Systems Engineering, Colorado State University, Fort Collins, CO, USA

WALTER SCOTT, JR. COLLEGE OF ENGINEERING
COLORADO STATE UNIVERSITY

Background

- Using a control co-design a novel optimization model was constructed to address important design and operation questions for a natural gas power plant with a carbon capture and thermal storage element.
- The goal of my project is to remove many of the non-essential elements of this optimization model, and make a simpler model that makes this project easier to communicate.

Methods

- DTQP is a MATLAB program that solves linear-quadratic dynamic optimization problems using direct transcription and quadratic programing.
- DTQP is the tool that this project was coded in and is a large part of it.
- I read through the paper, and I took out the cold storage aspect of the natural gas power plant, and separated out those equations from the whole.
- These equations were used to create the simplified model.

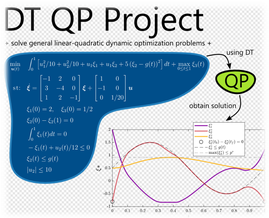

Figure 1. Diagram illustrating DTQP

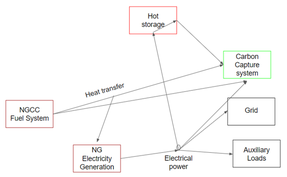

Figure 2. Natural gas power plant configuration

Results

```
26
27      % define A matrix
28
29      A = cell(2,2);
30      A{1,1} = 0;
31      A{1,2} = 0;
32      A{2,1} = 0;
33      A{2,2} = -1/tau;
34
35      % define b matrix
36
37      B = cell(2,3);
38      B{1,1} = khsin;
39      B{1,2} = -khsout;
40      B{1,3} = 0;
41      B{2,1} = 0;
42      B{2,2} = 1/tau;
43
44      % Mayer and Lagrage
45      Mayer = [c1,c2,c3];
46      Largrage = [c4,c5];
47
```

```
Greenhouse.m   Example3.m   Example22.m
49      L(1).right = 2;
50      L(1).left = 0;
51      L(1).matrix{1,1} = @(t) -c5(t);
52
53      L(2).right = 1;
54      L(2).left = 0;
55      L(2).matrix{1,1} = @(t) -c4(t);
56
57      % Mayer
58      M(1).right = 4;
59      M(1).left = 0;
60      M(1).matrix{1.1} =  c1;
61
62      % Operations
63
64      opst.general.plotflag = 1;
65      opts.general.saveflag = 0;
66      opts.dt.defects = 'DR';
67      opts.dt.quadrature = 'CDR';
68      opts.dt.mesh = 'ED';
69      opts.dt.nt = 25;
70
71      % upper and lower bounds
72
73
```

Figure 3. The MATLAB code for the simplified models as it stands

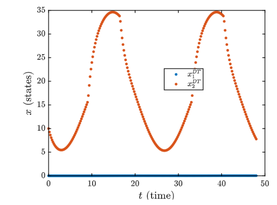

Figure 4. Example plot using the DTQP software

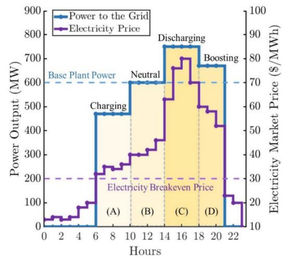

Figure 5. This figure shows the Operation phases of the power plant

- This project is currently ongoing and currently unfinished.
- Figure 5 shows a graph the describes the inevitable goal of this model. The figure has a purple line that shows the price of electricity at different discreate time values, in this case 1 hour, for the specific time horizon. The blue show the output of energy to the grid, corresponding to the energy price.
- Using this information about the energy price, we can model and optimize the power plants on and off behavior, the power generated with and without carbon capture, and fuel costs.
- In the simplified model, the figure will be similar to the one in figure 5, but it most notably will not have a boosting phase.

How do you plan to apply what you have learned?

The four main thing that I learned about during this project are, optimization, basic linear algebra and matrix math, DTQP, and MATLAB troubleshooting skills. Most of what I learned like the DTQP tool and basic optimization I plan to continue using as I continue work creating this simplified model. The other skills I've learned, such as MATLAB troubleshooting, I will be important in my career as a chemical engineer since MATLAB is an important tool for all engineers.

Next Steps

- The first of my next steps with this project is to go through the original paper and find values and equations for the upper and lower bounds and parameters.
- Currently I just have random numbers and functions as stand ins, but Id like to replaces those soon.
- I want to be able to get the program to calculate a solution as close to the original as I can. Finally, I would like to be able to write a short paper on this model if I continue this project into the summer.

```
% define time horizon
ti = 0; tf = 4;

% define made up problem parameters
c1 = 1;
c2 = 2;
c3 = 3;
c4 = cos;
c5 = sin;

uhsout = 1; % use eqatuions from pap
PP = 1; % use eqatuions from paper
khsin = 1; % use eqatuions from pape
khsout = 1; % use eqatuions from pap
tau = 1; % use eqatuions from paper
sshs = 1;
phsin = 1;

JL(1) = @(t) -c4(t).*(uhsout(t));
JL(2) = @(t) -c5(t).*(PP(tau));

M = (c1.*(sshs))+(c2.*(phsin))+c3;
```

Figure 6. Parameters needing to be replaced

Conclusions

- As this project is still ongoing there is not much information to draw from it to get a solid conclusion.
- Removing the boosting phase of the graph in figure 5, we can get an estimate of the behavior of the simpler model and can draw some tentative conclusions about what our simple model will look like.

What benefits did you get from your SURE experience?

This was definitely a great experience that came with a lot of benefits. Doing research in college was always something I've aspired to do, and having the change was amazing. I had a lot of fun on learning all about optimization and the DTQP tool, but the biggest benefits I got from this experience were collaboration skills, and most essentially, learning and not being afraid to ask for help when I needed it.

References & Acknowledgements

Dr. Herber's Slides

Limb, B. J., Markey, E., Vercellino, R., Garland, S., Pisciotta, M., Psarras, P., Herber, D. R., Bandhauer, T., & Quinn, J. C. (2022). Economic viability of using thermal energy storage for flexible carbon capture on natural gas power plants. *Journal of Energy Storage*, *55*, 105836. https://doi.org/10.1016/j.est.2022.105836

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